UM10874

SSL5231BDB1289 120 V 18 W dimmable buck non-isolated LED driver

Rev. 1 — 23 April 2015 **User manual**

Document information

Info	Content
Keywords	SSL5231BDB1289, SSL5231BT, dimmable, LED driver, buck converter, fixture, eco-THD
Abstract	This user manual describes the operation of the SSL5231BDB1289 120 V 18 W eco-THD dimmable LED driver featuring the SSL5231BT. The SSL5231BDB1289 demo board uses a buck topology.

Revision history

Rev	Date	Description
v.1	20150423	first issue

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1. Introduction

WARNING

Lethal voltage and fire ignition hazard

The non-insulated high voltages that are present when operating this product, constitute a risk of electric shock, personal injury, death and/or ignition of fire.

This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.

This user manual describes the operation of the SSL5231BDB1289 120 V 18 W eco-THD dimmable LED driver. The buck converter topology provides a simple and efficient solution for mains dimmable LED recessed light applications with a very good dimmer compatibility.

The SSL5231BDB1289 demo board complies with EMI and safety regulations.

Figure 2 shows dimensions of the SSL5231BDB1289 demo board. Figure 3 shows the top view and bottom view of the SSL5231BDB1289 demo board.

2. Safety warning

The demo board input is connected to the 120 V mains supply. Avoid touching the board while it is connected to the mains voltage and when it is in operation. An isolated housing is obligatory when used in uncontrolled, non-laboratory environments. Galvanic isolation from the mains phase using a fixed or variable transformer is always recommended. Figure 1 shows the symbols on how to recognize these devices.

a. Isolated b. Not isolated

Fig 1. Isolation symbols

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3. Specifications

Table 1 lists the specification of the SSL5231BDB1289 demo board.

Table 1. SSL5231BDB1289 specifications

Symbol	Parameter	Value
V_{mains}	AC mains supply voltage	120 V (AC); ±10 %
I_{mains}	AC mains input current	150 mA; ±5 %
V_{LED}	output voltage	48 V; ±10 %
I_{LED}	output current	325 mA
$\Delta I_{LED}/\Delta I_{LED(nom)Vmains}$	line regulation	> 3 % at V_{mains} ±10 %
$\Delta I_{LED}/\Delta I_{LED(nom)VLED}$	load regulation	> 3 % at V_{LED}; −10 %
η	efficiency	> 87 %
PF	power factor	> 0.95
T_{oper}	operating temperature	−40 °C to +85 °C
-	board dimensions	30 mm × 85 mm
-	conducted ElectroMagnetic Interference (EMI)	FCC15 class B
-	IEC61000-3-2	class C (for P_{in} < 25 W limit)

Figure 2 shows the dimensions of the demo board.

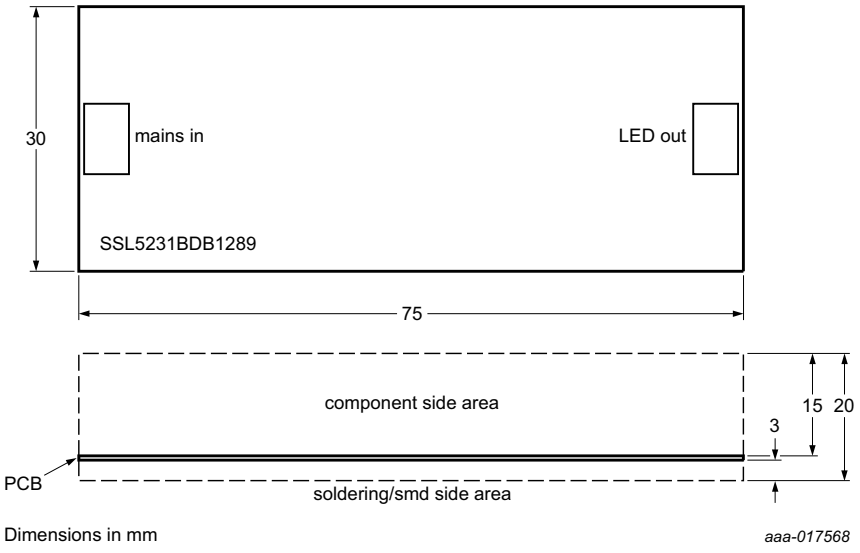

Fig 2. SSL5231BDB1289 demo board dimensions

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4. Board photographs

a. Top view

b. Bottom view

Fig 3. SSL5231BDB1289 demo board photographs

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5. Board connections

The SSL5231BDB1289 demo board is optimized for a 120 V/60 Hz supply. In addition to the mains voltage optimization, the board is designed to work with multiple LEDs or an LED module with a low forward voltage. The mains connection of the SSL5231BDB1289 demo board is different from other demo boards. Connect the mains to the screw connector X1.

Remark: The maximum rated voltage of the board is 150 V (AC).

The anode of the LED load is connected to pin 1 of connector X2. The cathode is connected to pin 2 of connector X2. Use an LED string with a typical forward voltage of 48 V/±10 % on the SSL5231BDB1289 demo board. Under the expected conditions, the output current is 325 mA when no dimmer is used.

It is possible to shorten the board by mounting C8 and C9 upright. Connector X2 can be mounted at a different position. The board becomes 10 mm shorter. If the board is shortened, wire bridge WB1 must be placed.

Fig 4. SSL5231BDB1289 board connections

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6. Functional description and options

6.1 Input filtering

Capacitors C1 and C2 and inductors L1 and L3 filter the switching current from the buck converter to the line. Capacitors C1 and C2 also provide a low-impedance path for the switching current. The value of capacitor C2 is selected so the application passes for both conducted and radiated EMI.

The 10 Ω input series resistance together with varistor MOV1 across the AC bridge rectifier input provides protection against transient surge voltages. To increase the immunity to line surges, the input resistance is added. Do not omit this resistor.

To improve dimming performance, an extra notch filter, inductor L3, capacitor C11, and resistor R2 is added to the input. The extra filter suppresses the common-mode disturbance in the 200 kHz to 300 kHz range. Furthermore, inductor L3 reduces the repetitive inrush current to maximum 2.3 A. The notch filter isolates capacitor C1 from the dimmer, improving the dimming performance.

6.2 Open-load protection

The driver board is protected when the LED load is accidentally left open. The open-load protection is a non-latched protection. It recovers when the LED string is reconnected. The LED current is not controlled when reconnecting which can destroy the LED string. So turn off the mains before reconnecting the LED load.

Two circuits set the open-load output voltage. One circuit sets the open output voltage when the IC does not operate because of a defect. The other circuit (OVP) sets it when the IC is operating normally. In all cases, the output voltage must never exceed the rated DC voltage of the output capacitor.

6.2.1 IC not operating

The voltage divider, consisting of resistors R19 and R20, sets the output voltage from the VCC pin of the IC to the GND pin of the IC and resistor R10.

$$V_o = (V_{bus} - V_{CC}) \cdot \frac{R10}{R10 + R19 + R20} \quad (1)$$

As a rule of thumb, limit resistor R10 to $\frac{n \times 2.5\ V}{2 \times 190\ \mu A}$.

In this way, the voltage is not sufficient to turn on the LEDs (n is the number of LEDs in series at the output).

Resistor R10 has a double function. It also supplies the dimmer reset circuit. If this circuit is not used, resistor R10 must be connected to GND. The extra offset of 1.2 V caused by V_{be} of transistor Q4 and resistor R6 can be neglected in the calculation.

The non-operating output voltage must not be equal to or exceed the voltage set by the operating mode. It is good practice to set the level in non-operating mode 5 V to 10 V lower than in operating mode.

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6.2.2 IC operating with OVP

When the voltage in the non-operating mode is set to a safe level for the output capacitor, the voltage in the operating mode can be set. The OVP is triggered when during four consecutive high-frequency cycles, 1.8 V is detected at the DEMOVP pin. The output voltage is set with Equation 2:

$$V_o = 1.8 \cdot \left(1 + \frac{R18}{R17}\right) \quad (2)$$

The output voltage must never exceed the rated DC voltage of the output capacitor. The preferred value for resistor R17 is 5.6 kΩ. Do not use a resistor value that exceeds 18 kΩ. The DEMOVP pin is a high-ohmic input, so it is sensitive to disturbance causing false OVP triggering.

6.3 LED current and sense resistor

To optimally profit from the excellent current stability of the SSL5231BT overtemperature, 50 ppm MELF type resistors are recommended to sense the LED current. The output current stability range drops to 3 % compared to 7 % over the full temperature range for normal 200 ppm 1210 type resistors.

6.3.1 Single resistor sensing

Figure 5 shows the principle of single resistor sensing. Single resistor sensing is the traditional way of sensing the peak current through the switch and inductor.

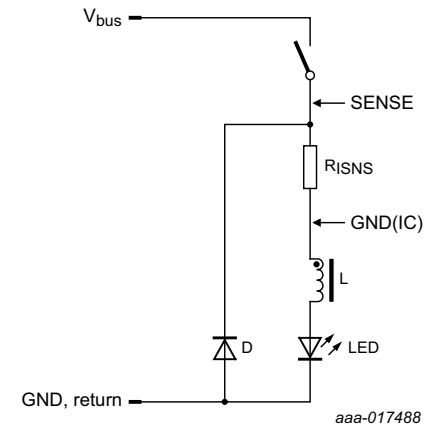

Fig 5. Single resistor sensing principle

The LED current for single resistor sensing is calculated with Equation 3:

$$I_{LED} = \frac{0.31}{R_{ISNS}} \quad (3)$$

When a dimmer is used, the typical maximum peak current that can be reached equals:

$$I_{peak(max)} = \frac{1.8}{R_{ISNS}} \quad (4)$$

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For this application, the LED current amounts 325 mA, which means a sense resistor of 0.9 Ω is required. Using this resistor value would result in a maximum peak current of $\frac{1.8\ V}{0.9\ \Omega} = 2.0\ A$.

The maximum allowed input current $I_{I(SW)}$ = 2 A limits the current through the switch of the IC. The peak current for the IC is too high. It also implies that inductor L2 must be used with a saturation current of at least 2 A. During normal operation, the peak current is approximately 4 times the average LED current (1.3 A). So an inductor saturation current of maximum 1.5 A is sufficient. To meet the requirements to lower the peak IC current and. the peak inductor current, split sense can be used. Split sense uses the existing head room in the peak current detection to lower the IC and inductor current.

6.3.2 Split resistor sensing

Figure 6 shows the principle of split resistor sensing. The peak of the primary stroke the inductor current flows through both sense resistors and during the secondary stroke the inductor current only flows through the secondary sense resistor.

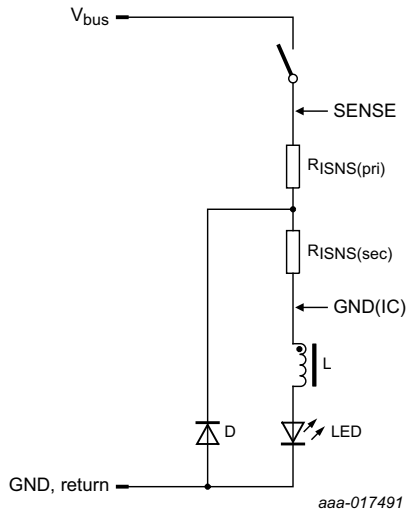

Fig 6. Split resistor sensing principle

When the split sense resistor configuration is set up to make maximum use of the overcurrent sense protection head room of the buck converter application, the IC still regulates to the average LED current. The average LED current measured by the voltage between the ISNS pin and the GND pin of the IC divided by the R_{ISNS} resistor. When the application is dimmed the converter shifts to peak current regulation. To regulate to the average LED current, the maximum achievable line and load regulation are maintained.

Equation 5 to Equation 8 for a buck converter can be used:

$$\frac{V_{ocp}}{I_{peak(inductor)}} = R_{ISNS[pri]} + R_{ISNS(\mathrm{sec})} + R_{bond} = R_{ISNS(tot)} \quad (5)$$

$$R_{ISNS(AV)} = \frac{0.31}{I_{LED(AV)}} \quad (6)$$

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$$R_{ISNS(AV)} = R_{ISNS(\mathrm{sec})} + \delta(R_{ISNS(pri)} + R_{bond}) \quad (7)$$

$$\delta = \frac{V_{LEDP}}{V_{bus}} \quad (8)$$

Where:

- R_{bond} is the bond wire resistance on the ISNS pin inside the IC
- $I_{peak(inductor)}$ can be calculated with the SSL5231BT calculation tool
- V_{ocp} can be found in the *SSL5231BT data sheet*. It is 1.8 V typical for the SSL5231BT

For a first set-up, assume:

- $I_{peak(inductor)} \approx 4 \times I_{LED(AV)}$
- $R_{bond} = 92\ \Omega$

To have some margin, $I_{peak(inductor)}$ must be ≤ 1.8 A. If $I_{peak(inductor)}$ exceeds 1.8 A, the IC already moves to peak current regulation during typical operation.

Based on Equation 5 to Equation 8, the following can be concluded:

$$R_{ISNS(pri)} = \frac{R_{ISNS(AV)} - R_{ISNS(tot)}}{(\delta - 1)} - R_{bond} \quad (9)$$

$$R_{ISNS(\mathrm{sec})} = R_{ISNS(tot)} - R_{ISNS(pri)} - R_{bond} \quad (10)$$

The extra advantage of the split sense configuration is that it improves the THD. The peak current drawn from the mains is shifted towards the middle of the half-mains period.

The disadvantage of using the split sense configuration in a buck converter is obvious. The bus voltage and the LED voltage determine the duty cycle. So the line regulation and load regulation is worse than for a single sense resistor application. The line regulation and load regulation are not affected in a buck boost converter application that uses split sense.

For the SSL5231BDB1289 demo board, the maximum peak current is limited to $I_{peak(reg)}$ = 1.33 A, according to:

$$I_{peak(reg)} = \frac{V_{I(max)ISNS}}{R_{ISNS(pri)} + R_{ISNS(\mathrm{sec})}} \quad (11)$$

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6.4 Dimmer zero level restore circuit

When the rectified AC line voltage drops to below the LED voltage, a buck converter-based application stops switching. The impedance towards the mains becomes high ohmic. To suppress peak voltages, most dimmers incorporate a filter capacitor in parallel to the switching device. Because the buck converter becomes high ohmic, this capacitor is not discharged properly. It remains charged to the LED voltage. If this capacitor is not discharged properly, deep dimming is hampered. The dimmer may not have a stable and small phase cut.

To overcome this problem, the circuit around transistor Q4 builds a discharge circuit or zero level restore circuit. It is not a bleeder circuit as it does not maintain the dimmer hold current. Transistor Q4 is set to conduct a maximum current of 20 mA. This current is set with:

$$I_{C(Q4)} = \frac{V_{be(Q2)} + V_{R5}}{R6} \quad (12)$$

The V_{be} voltage of transistor Q2 + the voltage across R5 is 0.6 V typical. Transistor Q2 regulates the current of transistor Q4.

When the voltage on V_{rect} exceeds V_{LED}, in this case 50 V, the voltage divider $\frac{R5}{R4 + R5}$ turns off transistor Q4. So transistor Q4 does not overheat and no efficiency decrease occurs.

Capacitor C4 is used to reduce the control bandwidth. So transistor Q4 does not oscillate at a high frequency, improving the conducted EMI significantly.

Resistor R10 supplies the zero restore circuit is supplied from the LED voltage. When the zero level restore circuit is not used, resistor R10 must be connected to GND.

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7. Performance

The performance was measured using an LED load with a 48 V forward at a 440 mA LED output current. Figure 7 to Figure 12 show the performance data.

7.1 Efficiency

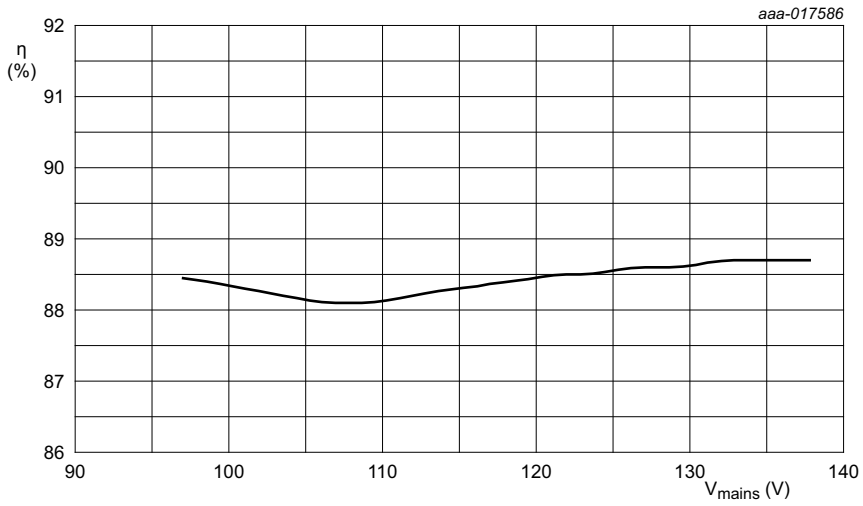

Fig 7. Efficiency as a function of AC mains input voltage

7.2 Power Factor

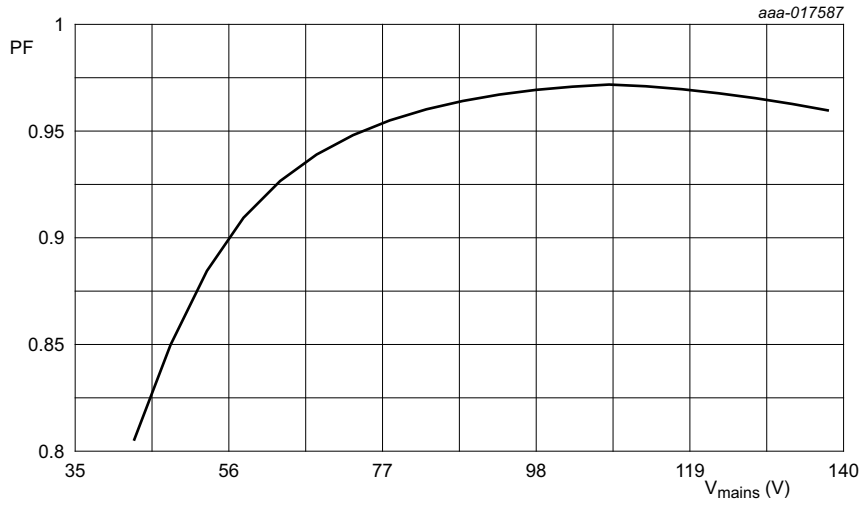

Fig 8. Power factor as a function of AC mains input voltage

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7.3 Line regulation

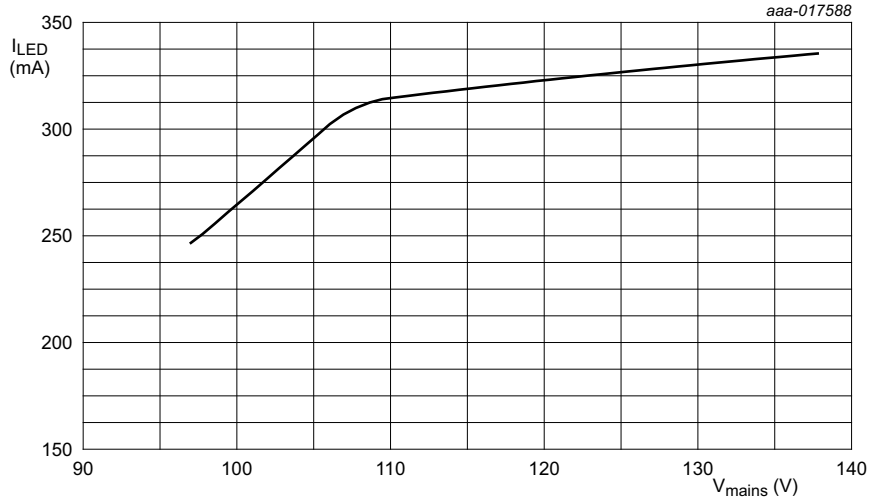
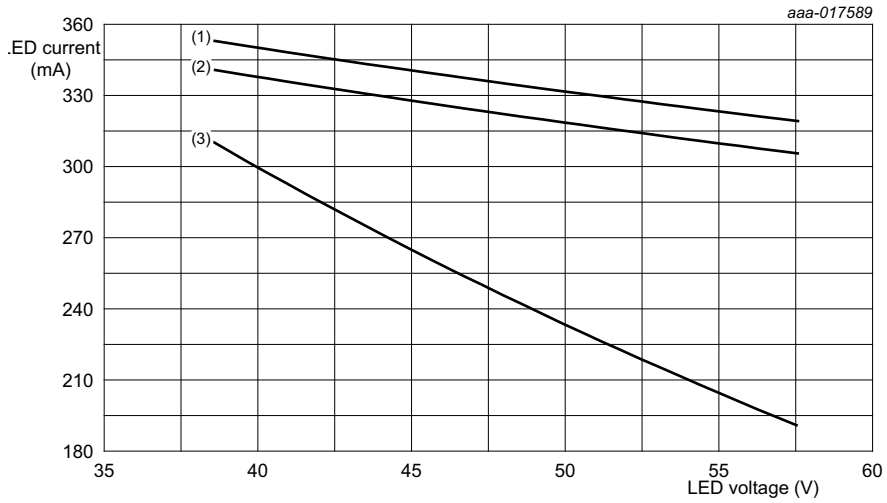


Fig 9. Output current as a function of AC mains input voltage

7.4 Load regulation



(1) 138 V_{mains}

(2) 120 V

(3) 96 V (dimmed output)

Fig 10. Output current as a function of output voltage at nominal mains

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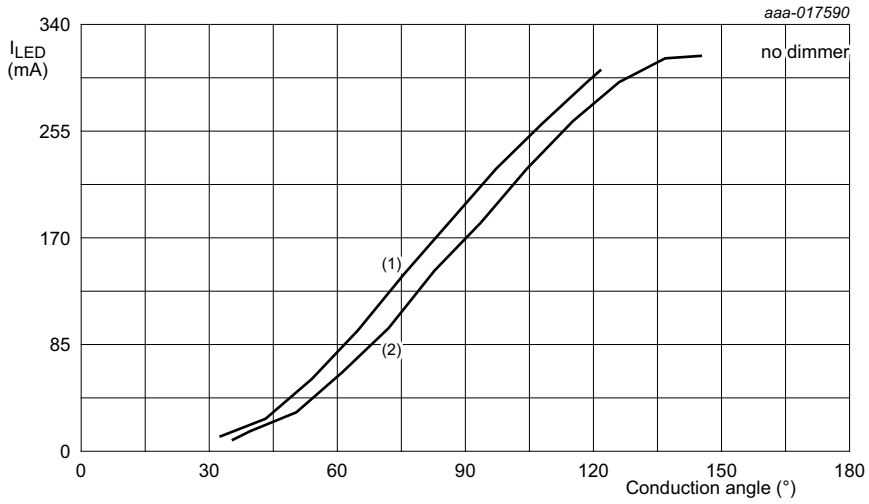
7.5 Dim curves

Figure 11 shows the output current when a leading-edge dimmer or a trailing-edge dimmer is used. The output current without dimmer is also indicated.



(1) Trailing-edge

(2) Leading-edge

Fig 11. Output current as a function of dimmer angle

Dimming compatibility includes smooth dimming without any flashing or flickering effects across the complete dimming range. The SSL5231BDB1289 demo board has been tested with a wide selection of dimmers. It is compatible with most leading-edge and trailing-edge dimmers on the market.

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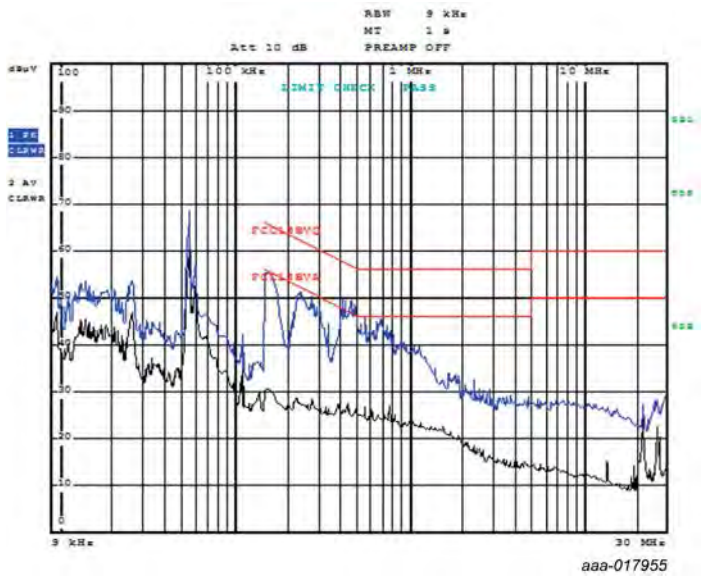
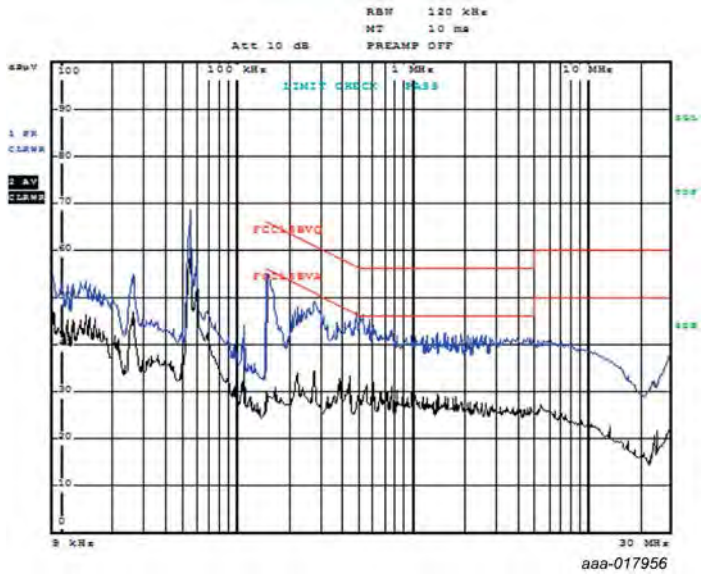
7.6 ElectroMagnetic Interference (EMI)

The ElectroMagnetic Interference (EMI) was measured according to the FCC15 class B standard. The board complies with the requirements. Figure 12 shows the measurement results.



a. AC mains (Live)



b. AC mains (Neutral)

Fig 12. Conducted EMI performance

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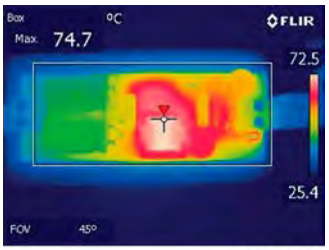
7.7 Thermal images

The thermal images are taken after a settling time of 1 hour and in dimmed and undimmed conditions.



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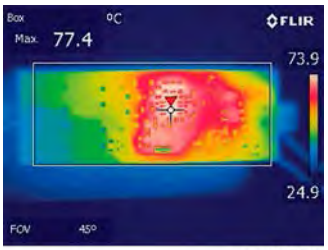
a. 18 W no dimming top view; Hottest spot: The buck inductor L2



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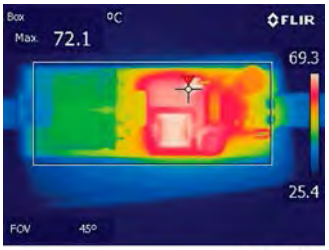
b. 18 W no dimming bottom view; Hottest spot: the SSL5231BT



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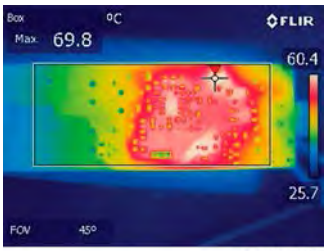
c. 90° leading-edge dimmed top view; Hottest spot: Latch resistor R7



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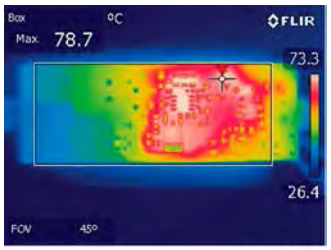
d. 90° leading-edge dimmed bottom view; Hottest spot: Diode D2



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e. Dimming to 15 W; Hottest spot: Diode D2

Fig 13. Thermal images

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8. Protections

The IC incorporates the following protections:

- UnderVoltage Lockout (UVLO)
- Cycle-by-cycle OverCurrent Protection (OCP)
- Internal OverTemperature Protection (OTP)
- Cycle-by-cycle maximum on-time protection
- Output OverVoltage Protection (OVP)
- Output Short Protection (OSP)

For more detailed information about the IC protections, see the *SSL5231BT data sheet* (Ref. 1).

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9. Schematic

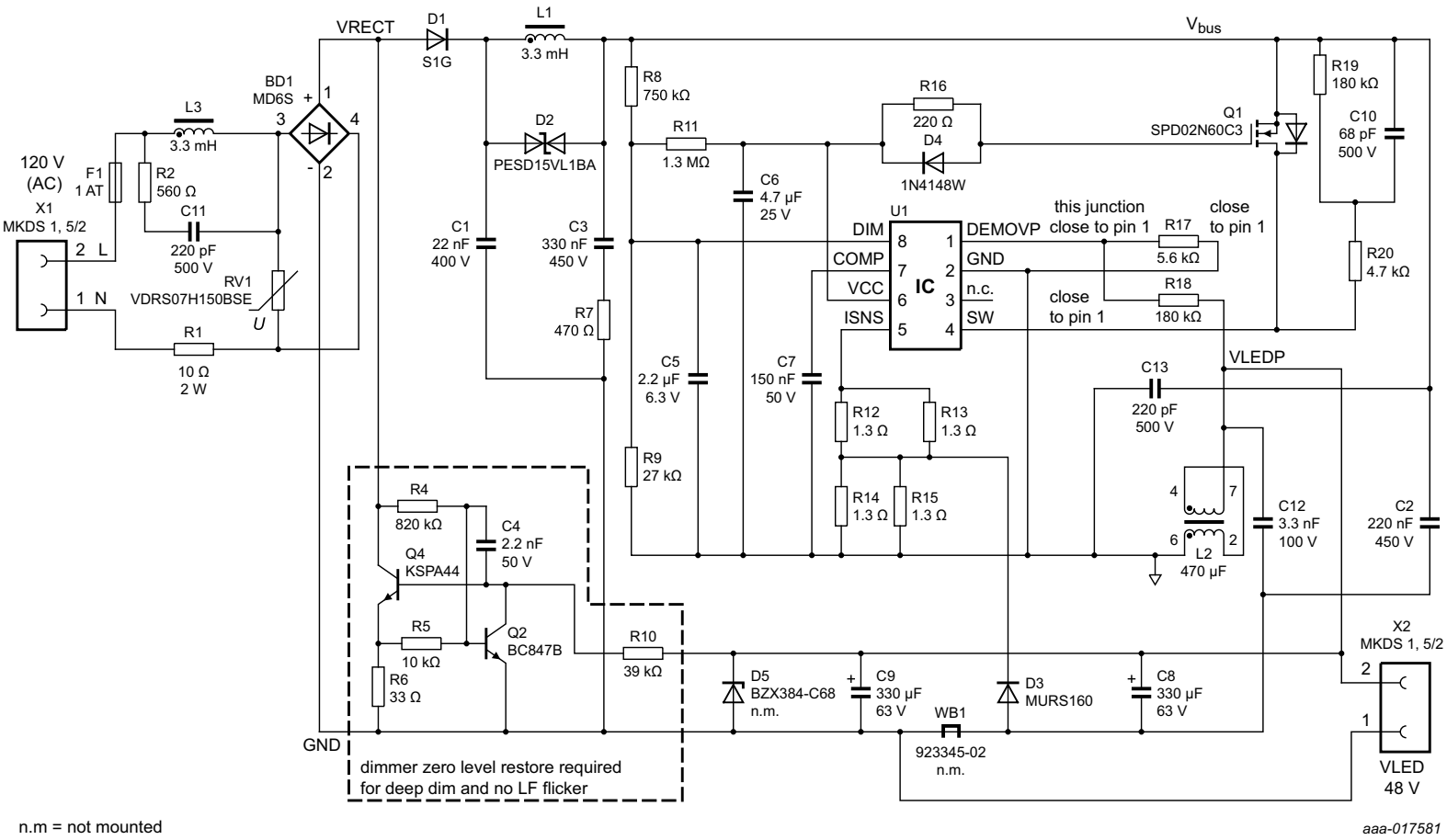

Fig 14. SSL5231BDB1289 minimum component count schematic diagram

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10. Bill Of Materials (BOM)

Table 2. SSL5231BDB1289 demo board full BOM

Reference	Description and values	Part number	Manufacturer
BD1	bridge rectifier; 1 kV; 500 mA	MD5S	Rectron
C1	capacitor; 22 nF; 5 %; 400 V; PET; THT	ECQE4223JF	Panasonic
C2	capacitor; 220 nF; 5 %; 450 V; PET; THT	ECWF2W224JAQ	Panasonic
C3	capacitor; 330 nF; 10 %; 450 V; PET; THT	ECWFD2W334KQ	Panasonic
C4	capacitor; 2.2 nF; 10 %; 50 V; X7R; 0603	-	-
C5	capacitor; 2.2 μF; 10 %; 6.3 V; X7R; 0603	C1608X7R0J225K080AB	TDK
C6	capacitor; 4.7 μF; 10 %; 25 V; X7R; 0805	C2012X7R1E475K125AB	TDK
C7	capacitor; 150 nF; 10 %; 50 V; X7R; 0603	-	-
C8; C9	capacitor; mount horizontal; 330 μF; 20 %; 63 V; ALU; THT	UPW1J331MHD	Nichicon
C10	capacitor; 68 pF; 1 %; 500 V; C0G; 0805	CBR08C680FCGAC	KEMET
C11; C13	capacitor; 220 pF; 5 %; 500 V; C0G; 1206	12067A221JAT2A	AVX
C12	capacitor; 3.3 nF; 10 %; 100 V; X7R; 0603	-	-
D1	diode; 280 V; 1 A	S1G-E3/61T	Vishay
D2	diode; TVS; 15 V	PESD15VL1BA	NXP Semiconductors
D3	diode; 600 V; 1 A	MURS160-E3-52T	Vishay
D4	diode; 100 V; 300 mA	1N4148W-7-F	Diode Inc.
D5	diode; zener; 68 V; 300 mA	BZX384-C68	NXP Semiconductors
F1	fuse; slow-blow; 1 A	MST 1A 250V	Multicomp
L1	inductor; mount horizontal; 3.3 mH; 280 mA	744772332	Würth Elektronik
L2	transformer; 350 μH; 5 %	750341594	Würth Elektronik
L3	inductor; 3.3 mH; 190 mA	13R335C	Murata
Q1	MOSFET-N; 650 V; 1.8 A	SPD02N60C3	Infineon
Q2	transistor; NPN; 45 V; 100 mA	BC847B	NXP Semiconductors
Q4	transistor; NPN; 400 V; 300 mA	KSPA44TA	Fairchild
R1	resistor; 10 Ω; 10 %; 2 W; THT	EMC2-10RK	Welwyn Components
R2	resistor; 560 Ω; 5 %; 250 mW; 1206	-	-
R4	resistor; 820 kΩ; 1 %; 250 mW; 1206	-	-
R5	resistor; 10 kΩ; 1 %; 63 mW; 0603	-	-
R6	resistor; 33 Ω; 1 %; 250 mW; 1206	-	-
R7	resistor; 470 Ω; 5 %; 2 W; THT	ROX2SJ470R	TE Connectivity
R8	resistor; 750 kΩ; 1 %; 250 mW; 1206	-	-
R9	resistor; 27 kΩ; 1 %; 63 mW; 0603	-	-
R10	resistor; 39 kΩ; 1 %; 250 mW; 1206	-	-
R11	resistor; 1.3 MΩ; 1 %; 63 mW; 0603	-	-
R12; R13; R14; R15	resistor; 1.3 Ω; 1 %; 250 mW; 1206	-	-
R16	resistor; 220 Ω; 1 %; 63 mW; 0603	-	-

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Table 2. SSL5231BDB1289 demo board full BOM *...continued*

Reference	Description and values	Part number	Manufacturer
R17	resistor; 5.6 kΩ; 1 %; 63 mW; 0603	-	-
R18; R19	resistor; 180 kΩ; 1 %; 250 mW; 1206	-	-
R20	resistor; 4.7 kΩ; 1 %; 250 mW; 1206	-	-
RV1	resistor; VDR; 150 V; 20 J	VDRS07H150BSE	Vishay
U1	dimmable LED Driver; SSL5231BT	SSL5231BT	NXP Semiconductors
WB1	wire bridge; 0.8 mm; P = 5.08 mm	923345-02	3M
X1; X2	connector; terminal block; 5.00 mm	1715022	Phoenix Contact

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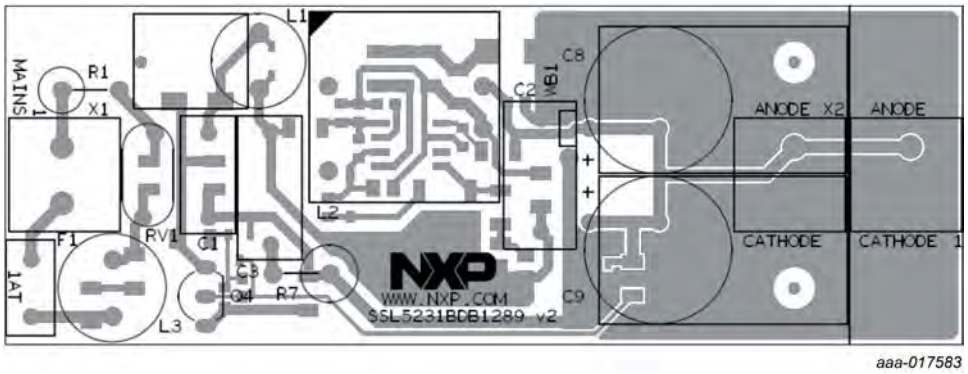
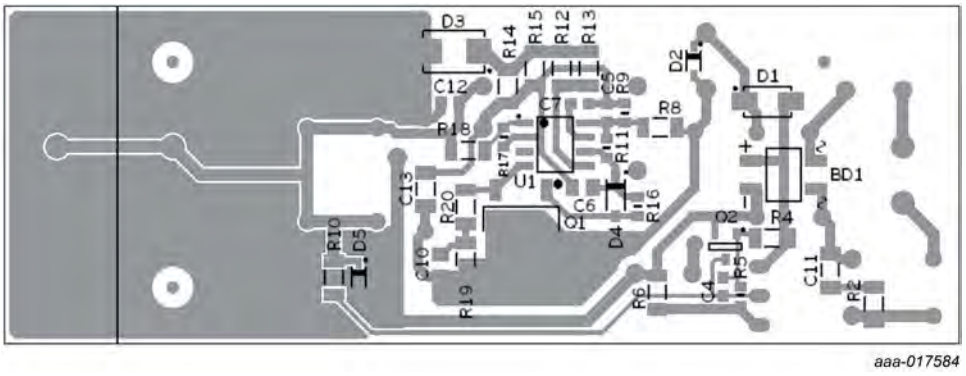
11. Board layout

Figure 15 shows the SSL5231BDB1289 demo board layout and assembly on both sides. Inductors L1, L2, and L3 can be mounted either vertically or horizontally.



a. Top view



b. Bottom view

Fig 15. SSL5231BDB1289 demo board assembly

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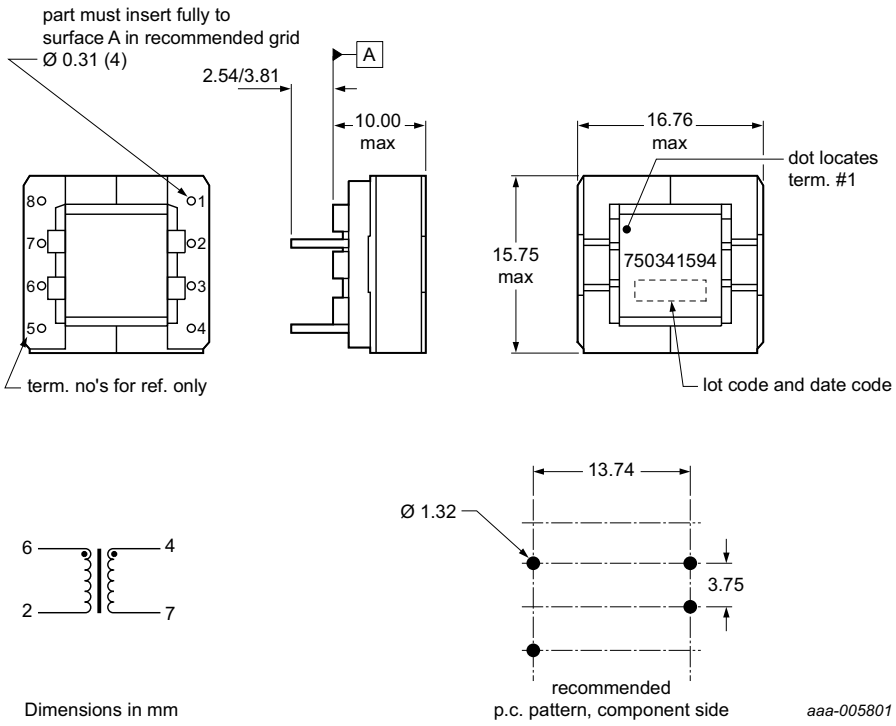
12. Inductor specifications

12.1 Inductor layout and dimensions



(1) Dimensions in mm.

Fig 16. Inductor layout and dimensions

12.2 Electrical specifications

Table 3. Test specifications

At 25 °C unless stated otherwise

Parameter	Test conditions	Value
DC resistance; 6 to 2	at 20 °C	0.717 Ω maximum
DC resistance; 4 to 7	at 20 °C	0.272 Ω maximum
Inductance; 6 to 2	20 kHz; 1 V (AC); L_a	350 μH; ±5 %
Dielectric; 2 to 4	1800 V (AC); 1 second	-
Turns ratio	(6 to 2):(4 to 7)	6:1 ±2 %

Remark: Operating temperature range: −40 °C to +125 °C including temperature range.

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13. Abbreviations

Table 4. Abbreviations

Acronym	Description
EMI	ElectroMagnetic Interference
LE	Leading-Edge
LED	Light-Emitting Diode
MELF	Metal Electrode Leadless Face
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
OCP	OverCurrent Protection
OSP	Output Short Protection
OTP	OverTemperature Protection
OVP	OverVoltage Protection
PF	Power Factor
SMD	Surface-Mounted Devices
SSL	Solid-State Lighting
TE	Trailing-Edge
THD	Total Harmonic Distortion
UVLO	UnderVoltage LockOut

14. References

[1] SSL5231BT data sheet — Compact high power factor dimmable LED driver IC

[2] AN11618 application note — SSL523XT buck-boost controller

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